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Operational Considerations for the Standby Diver in CUMA Dives

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Defence R&D Canada
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Abstract

The Canadian Underwater Minecountermeasures (MCM) Apparatus (CUMA) is a self-contained, semi-closed circuit breathing apparatus in service with the Canadian Forces (CF) and other North Atlantic Treaty Organization (NATO) Navies for MCM diving to a depth of 81 metres of seawater (msw) using a mixture of helium and oxygen. Current CF rules state that a diver completing more than 30 minutes (min) of oxygen decompression has to be accompanied by a standby diver at the 9 metre decompression stop. As there are no specific repetitive diving rules governing such shallow dives on CUMA, the procedure of adding bottom times to determine the decompression requirements of a second dive must be used. As a result, the standby diver may become unavailable for a subsequent dive to deeper depths. This affects the operational ability of a small team to continue diving as the divers, including the standby become 'dived out' too quickly. Experimental dives to 9 msw to simulate a standby diver accompanying a CUMA diver were conducted in the DRDC Toronto Dive Research Facility to measure the inspired partial pressure of oxygen (PiO_2). The results showed that the time-weighted average PiO_2 after 30 min at 9 msw was greater than 1.3 atmospheres (absolute) (ATA). As a result the inert gas loading should be minimal and there should be little or no decompression penalty associated with the standby diver diving again as a working CUMA diver. This will increase the operational ability of a small dive team to continue diving operations.

Résumé

L'appareil canadien de déminage sous-marin (ACDSM) est un appareil respiratoire autonome à circuit semi-fermé utilisé par les Forces canadiennes (FC) et par d'autres marines de l'Organisation du traité de l'Atlantique Nord (OTAN) pour effectuer des opérations de déminage sous-marin jusqu'à une profondeur de 81 mètres d'eau de mer. Cet appareil fournit un mélange d'hélium et d'oxygène. À l'heure actuelle, les règlements des FC stipulent que tout plongeur devant effectuer plus de 30 minutes de décompression à l'oxygène doit être accompagné par un plongeur en alerte au palier de décompression de neuf mètres. Puisqu'il n'existe aucune réglementation spécifique régissant les plongées successives d'aussi faible profondeur avec l'ACDSM, il faut utiliser la procédure qui consiste à additionner les temps de plongée pour déterminer le temps de décompression requis lors de plongées successives. Par conséquent, il se peut donc que le plongeur en alerte ne puisse effectuer de plongée subséquente à de plus grandes profondeurs. Cela a un impact négatif sur la capacité opérationnelle d'une petite équipe, puisque les plongeurs, y compris les plongeurs en alerte, atteignent trop rapidement le maximum permis. Pour simuler un plongeur en alerte accompagnant un plongeur utilisant un ACDSM, des plongées d'essai ont été effectuées à neuf mètres d'eau de mer à l'Installation de recherche en plongée de Recherche et développement pour la défense Canada – Toronto dans le but de mesurer la pression partielle d'oxygène inspiré (PiO_2). Les résultats ont démontré que la PiO_2 moyenne pondérée dans le temps était supérieure à 1,3 ATA (atmosphère absolue) après 30 minutes à neuf mètres d'eau de mer. L'accumulation de gaz inerte devrait donc être minimale et se traduire par une pénalité de décompression faible ou nulle pour un plongeur en alerte effectuant une plongée subséquente avec un ACDSM. La capacité opérationnelle d'une petite équipe de plongée s'en trouve ainsi augmentée.

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Executive summary

Operational Considerations for the Standby Diver in CUMA Dives:

R.Y. Nishi; A.J. Ward; D.J. Eaton; DRDC Toronto TM 2010-082; Defence R&D Canada – Toronto; November 2010.

Introduction or background: The Canadian Underwater Minecountermeasures (MCM) Apparatus (CUMA) is a self-contained, semi-closed circuit breathing apparatus in service with the Canadian Forces (CF) and other North Atlantic Treaty Organization (NATO) Navies for MCM diving to a depth of 81 metres of seawater (msw) using a mixture of helium and oxygen. Current CF rules state that a diver completing more than 30 minutes (min) of oxygen decompression has to be accompanied by a standby diver at the 9 metre decompression stop. As there are no specific repetitive diving rules governing such shallow dives on CUMA, the procedure of adding bottom times to determine the decompression requirements of a second dive must be used. As a result, the standby diver may become unavailable for a subsequent dive to deeper depths. This affects the operational ability of a small team to continue diving as the divers, including the standby become ‘dived out’ too quickly. Experimental dives to 9 msw to simulate a standby diver exposure were conducted in the Defence R&D Canada – Toronto (DRDC Toronto) Dive Research Facility to measure the inspired partial pressure of oxygen (PiO_2) and determine the decompression requirements for subsequent diving.

Results: Four dives were carried out (12 man-dives). The divers, all wearing CUMA sets, were pressed to a maximum depth of 12 msw for 5 min, followed by a stay at 9 msw of approximately an hour. This simulated the standby diver going down to meet the CUMA diver and then accompanying the CUMA diver to the 9 msw stop for the duration of the decompression stop. The results showed that the time-weighted average (TWA) PiO_2 was greater than 1.3 atmospheres (absolute) (ATA) after 30 min at 9 msw and greater than 1.5 ATA at 60 min or longer.

Significance: As a result of the observed high TWA PiO_2 , the inert gas loading resulting from the standby exposure should be minimal and there should be little or no decompression penalty associated with the standby diver diving again as a working CUMA diver. The standby diver should be able to dive again as a “clean” diver 30 min after surfacing from the standby dive, providing that at least 30 min was spent at 9 msw. Alternatively, the diver can also continue to dive again as a standby diver any number of times instead of as a working CUMA diver since the exposure at 9 msw is a no-decompression dive. This will increase the operational ability of a small dive team to continue diving operations and make more efficient use of diving personnel.

Sommaire

Considérations opérationnelles quant au plongeur en alerte lors de plongées avec ACDSM

R.Y. Nishi; A.J. Ward; D.J. Eaton; DRDC Toronto TM 2010-082; R & D pour la défense Canada – Toronto; Novembre 2010.

Introduction ou contexte : L'appareil canadien de déminage sous-marin (ACDSM) est un appareil respiratoire autonome à circuit semi-fermé utilisé par les Forces canadiennes (FC) et par d'autres marines de l'Organisation du traité de l'Atlantique Nord (OTAN) pour effectuer des opérations de déminage sous-marin jusqu'à une profondeur de 81 m d'eau de mer. Cet appareil fournit un mélange d'hélium et d'oxygène. À l'heure actuelle, les règlements des FC stipulent que tout plongeur devant effectuer plus de 30 minutes de décompression à l'oxygène doit être accompagné par un plongeur en alerte au palier de décompression de neuf mètres. Puisqu'il n'existe aucune réglementation spécifique régissant les plongées successives d'aussi faible profondeur avec l'ACDSM, il faut utiliser la procédure qui consiste à additionner les temps de plongée pour déterminer le temps de décompression requis lors de plongées successives. Par conséquent, il se peut donc que le plongeur en alerte ne puisse effectuer de plongée subséquente à de plus grandes profondeurs. Cela a un impact négatif sur la capacité opérationnelle d'une petite équipe, puisque les plongeurs, y compris les plongeurs en alerte, atteignent trop rapidement le maximum permis. Pour simuler le degré d'exposition d'un plongeur en alerte, des plongées d'essai ont été effectuées à neuf mètres d'eau de mer à l'Installation de recherche en plongée de Recherche et développement pour la défense Canada – Toronto dans le but de mesurer la pression partielle d'oxygène inspiré (PiO_2) et de déterminer les temps de décompression requis lors de plongées subséquentes.

Résultats : Quatre plongées ont été effectuées (douze plongées-personne). Les plongeurs, tous munis d'un ACDSM, ont été exposés à une pression équivalant à une profondeur maximale de douze mètres d'eau de mer pendant cinq minutes, puis à une profondeur de neuf mètres d'eau de mer pendant une heure pour simuler l'exposition d'un plongeur en alerte qui va rejoindre un plongeur muni d'un ACDSM et l'accompagne au palier de neuf mètres d'eau de mer pendant toute la durée de la décompression. Les résultats ont démontré que la PiO_2 moyenne pondérée dans le temps était supérieure à 1,3 ATA (atmosphère absolue) après 30 minutes à neuf mètres d'eau de mer et supérieure à 1,5 ATA après 60 minutes ou plus.

Importance : Grâce à la PiO_2 moyenne pondérée dans le temps élevée observée, l'accumulation de gaz inerte résultant de l'exposition en alerte devrait donc être minimale et se traduire par une pénalité de décompression faible ou nulle pour un plongeur en alerte effectuant une plongée subséquente avec un ACDSM. Trente minutes après avoir fait surface, le plongeur en alerte devrait pouvoir plonger de nouveau s'il a passé au moins 30 minutes à neuf mètres d'eau de mer. Il est également possible pour le plongeur de demeurer plongeur en alerte lors de ses plongées subséquentes plutôt que de plonger avec un ACDSM, car l'exposition à neuf mètres d'eau de mer ne requiert pas de décompression. La capacité opérationnelle d'une petite équipe de plongée s'en trouve ainsi augmentée et le personnel est ainsi utilisé de manière plus efficace.

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1 Introduction

Current Canadian Forces (CF) rules state that a diver completing more than 30 minutes (min) of in-water oxygen decompression has to be accompanied by a standby diver at the 9 metre decompression stop [1]. The Canadian Underwater Minecountermeasures Apparatus (CUMA) is a self-contained, semi-closed circuit breathing apparatus in service with the CF and other North Atlantic Treaty Organization (NATO) Navies for mine countermeasures (MCM) diving to a depth of 81 metres of seawater (msw) using a mixture of helium and oxygen. The decompression tables currently in use with the CF and other NATO Navies are CF Table 10 – No Decompression, CF Table 11 – In-Water Oxygen Decompression, CF Table 12 – Surface Decompression with Oxygen, and CF Table 14 – Repetitive Dive Table for Surface Intervals from 3 to 6 Hours [2]-[5]. With the exception of CF Table 10, these tables require the CUMA diver to switch to 100% oxygen during decompression at 9 msw. This decompression stop ranges from 4 min to approximately 95 min for CF Table 11 and to approximately 30 min for CF Tables 12 and 14.

As there are no specific repetitive diving rules governing such shallow dives on CUMA, the procedure of adding bottom times to determine the decompression requirements of a second dive must be used. As a result, the standby diver may become unavailable for a subsequent dive to deeper depths. This affects the operational ability of a small team to continue diving as the divers, including the standby diver, become ‘dived out’ too quickly. For a standby diver using CUMA with the inspired partial pressure of oxygen (PiO_2) over 1.0 atmospheres (absolute) (ATA), the inert gas loading from these shallow accompanying dives should be minimal and there should be little or no decompression penalty associated with the standby diver diving again as a regular CUMA diver. Although not explicitly stated, the standby diver could be treated as a normal CUMA diver and dive again on CF Table 14 after 3 hours on the surface [4] and as a new diver after 6 hours [3].

Several shallow CUMA dives were conducted in the Defence R&D Canada – Toronto (DRDC Toronto) Dive Research Facility (DRF) to simulate the use of a standby diver in MCM operations. The aim of these dives was to look at the PiO_2 to determine the inert gas loading and confirm theoretical calculations based on the CUMA decompression model that the impact on the decompression status of the standby diver would be minimal if a subsequent dive were to be conducted. This will increase the operational ability of a small dive team to continue diving operations.

2 Methods

2.1 Dive Subjects

The standby trials were conducted in conjunction with experimental dives to validate CUMA decompression tables to 84 msw [6] and used some of the same subjects. Eight subjects participated in these standby trials – one from DRDC Experimental Diving Unit (EDU), two from Fleet Diving Unit (Pacific) (FDU(P)), three from the Royal Australian Navy (RAN), and two from the Royal Navy (RN). All were male volunteers aged between 27 and 39 years of age, qualified by their respective navies to dive with re-breathers. All subjects supplied medical documentation from their Command stating their fitness to dive that was reviewed by the attending Diving Medical Officer.

Prior to the 84 msw experimental dive trials, medical assessments that included age, height, weight and skin fold calliper measurements were carried out on all subjects. These are shown in Table 1. All visiting divers also received three days training and indoctrination in the experimental procedures and the use of CUMA prior to the start of the 84 msw dive trials.

Table 1. Subject Affiliation and Characteristics

Diver Code	Affiliation	Sex	Age (yr)	Weight (kg)	Height (cm)	Biceps (mm)	Triceps (mm)	Sub-scapula (mm)	Supra-iliac (mm)	BMI	% Body Fat	Tobacco No. of cig/day
186	DRDC	M	38.6	81.5	172	6.5	6.5	11.5	8.5	27.5	17.16	0
165	FDU(P)	M	37.1	83.5	180	8.0	7.0	18.0	11.0	25.7	20.17	0
166	FDU(P)	M	27.9	79.0	172	7.0	14.0	10.0	16.0	26.7	18.11	0
26	RAN	M	28.2	91.5	181	8.0	11.0	11.0	8.0	27.9	15.55	0
27	RAN	M	26.5	96.5	187	6.0	10.0	11.0	8.0	27.5	14.56	0
29	RAN	M	31.1	75.5	173	8.0	15.0	15.0	11.0	25.2	21.31	0
117	RN	M	37.4	88.5	177	8.0	9.5	10.0	9.5	28.2	18.35	1-10
118	RN	M	36.6	98.0	172	11.0	17.0	24.0	22.0	33.1	25.72	11-20
Average			36.5	85.3	175	9.6	12.6	14.4	13.9	27.7	21.60	
Standard Deviation			6.3	10.0	6	3.4	3.7	4.5	6.2	2.3	4.83	

% Bodyfat calculations from "Body fat assessed from total body density and its estimation from skinfold thickness:" J.V.G.A. DURNIN and J. WOMERSLEY Br. J. Nutr. (1974), 32, 77

2.2 Procedures

The experimental dives were approved by the DRDC Toronto Human Research Ethics Committee [6]. All dives were carried out in the DRDC Toronto (DRF) in accordance with EDU Experimental Operational Orders. The water temperature for all dives was between 6-8°C.

Each dive consisted of 2 wet divers (fully immersed, resting) and a standby diver (partially wet, resting) on the CUMA breathing apparatus and a dry Team Leader breathing air. The standby diver was also considered to be a dive subject since no work was involved. The aim of these dives was to simulate the profile that a standby diver may be expected to conduct in the field when accompanying a CUMA diver at the 9 msw in-water decompression after a long, deep dive. These divers descended to a maximum depth of 12 msw for 5 min to simulate going down to the 12

msw stop to meet the CUMA diver and then travelled to 9 msw for a planned bottom time of 94 min corresponding to the in-water oxygen (O_2) decompression stop for the 81 msw/20 min dive from CF Table 11.

Prior to each dive, each CUMA set was bench tested and calibrated. The carbon dioxide (CO_2) scrubber was charged using soda lime (Molecular Products Limited Sofnolime 8-12 Mesh) meeting CF specifications [7]. On completion of the calibrations and bench tests, the CUMA sets were assembled, leak tested and the integrity of the apparatus confirmed by a qualified EDU technician. The CUMA sets were then transferred to the DRF and connected to the data acquisition tether.

The subjects were briefed prior to each dive. The wet divers and standby diver were then dressed in well-fitting neoprene dry suits, thermal underwear, gloves and hood and entered the dive chamber. They donned their CUMA and each gas supply was switched on at a maximum of 5 min before descent, so as to keep O_2 pre-breathing to a minimum. The dive subjects entered the water and were checked for leaks. On completion of the leak test, the divers moved to their designated positions in preparation for descent. The wet divers stood fully submerged on the wet side of the barrier while the standby diver remained semi-submerged to the waist in the intermediate area on the dry side of the barrier. Once in position, the divers were ordered to empty their counterlungs and fill them with the bypass gas mix of 80:20 helium-oxygen (HeO_2). This is standard procedures for CUMA diving, and ensures that the diver does not dive with the elevated partial pressure of oxygen (PO_2) from the pure O_2 that has been supplied while on the surface. On completion, the DRF was pressurized.

The planned descent rate was $18 \text{ msw} \cdot \text{min}^{-1}$. On arrival at 12 msw, all divers inflated their counterlungs using the bypass valve until the counterlung relief valve lifted, again in accordance with CUMA drills in order to remove any PO_2 spike produced by gas concentration inertia during descent. Wet divers were allowed to move around within the wet chamber but were not permitted to carry out work cycles on the bicycle ergometers. After 5 minutes at 12 msw, including the descent, the chamber was brought up to 9 msw. On completion of the 9-msw stop, the chamber was brought to the surface.

The partial pressures of inspired O_2 (PiO_2) and inspired CO_2 ($PiCO_2$) were continuously monitored for all subjects on CUMA for the full duration of each dive. A description of the data acquisition system is given in Annex A.

Post-dive Doppler ultrasound monitoring for decompression-generated bubbles was not carried out on the subjects as the wet and standby divers were breathing a high level of oxygen from the CUMA set and there was no risk of decompression sickness.

3 Results and Discussion

3.1 Time-weighted average PiO_2

Four dives were carried out. Figure 1 shows the PiO_2 observed on one of the dive subjects during these dives. (Figures A1 and A2 in Annex A show the results for all divers.) The time spent at 9 msw was truncated at around 60 min since the PiO_2 was observed to have reached a fairly steady value after about 25 min into the dive. Unlike a normal CUMA dive to deeper depths, the PiO_2 is lowest at the beginning of the dive and gradually builds up to the PO_2 level being delivered by the breathing loop (1.6 ATA, with a range from 1.5 to 1.7 ATA). Since the standby diver role is to accompany a CUMA diver completing more than 30 min of in-water oxygen decompression, it can be seen that the PiO_2 will have reached a relatively steady-state value by 20 to 25 min at 9 msw. As the standby diver will not be doing any work except to maintain position at the 9 msw stop, the PiO_2 value should not vary very much after this point. In order to determine whether or not the standby diver can subsequently dive again as a working CUMA diver, it is necessary to look at the time-weighted average (TWA) PiO_2 from the start of the dive.

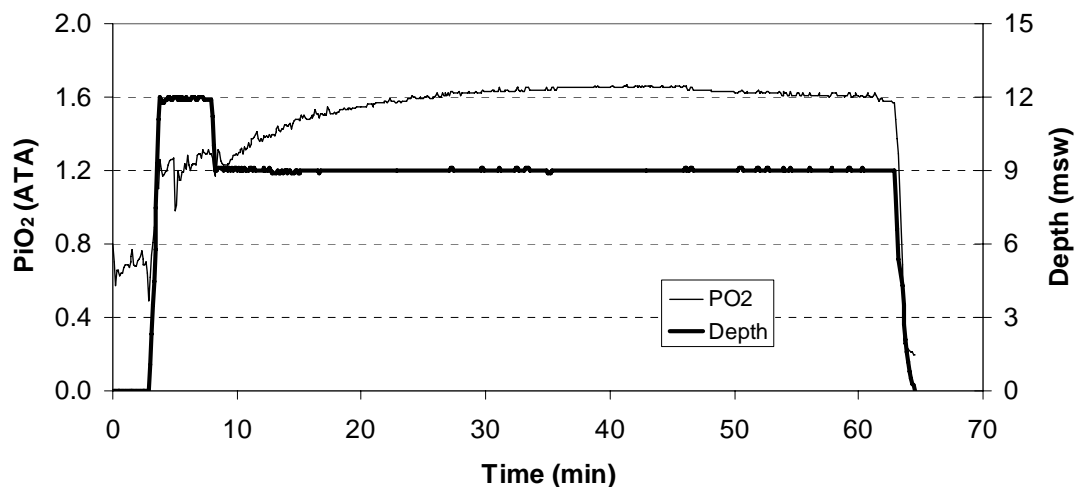


Figure 1. Example of inspired PO_2 (PiO_2) for a standby diver accompanying a CUMA diver during the in-water decompression stop at 9 msw.

Table 2 shows a summary of the TWA PiO_2 for the experimental divers from the start of the dive for different elapsed times from the start of the dive. Within 10 min of the start of the dive (i.e., after 5 min at 9 msw), the TWA PiO_2 should be greater than 1.1 ATA for most divers. On average, the TWA PiO_2 for this group of divers was greater than 1.3 ATA after approximately 10 min at 9 msw and greater than 1.5 ATA by 30 min at 9 msw. If the data and calculations are extrapolated to 95 min at 9 msw (the in-water stop required for the 81 msw/20 min dive from CF Table 12), the average TWA PiO_2 would be about 1.6 ATA and the minimum around 1.5 ATA.

Table 2. Time-weighted average PiO_2 from start of dive

N = 12 divers	TWA PiO_2 at 12 msw	Time-weighted average PiO_2 (ATA) for 5 min at 12 msw and selected times (in minutes) at 9 msw						
		5	10	15	20	25	30	40
Average	1.10	1.21	1.31	1.39	1.45	1.49	1.52	1.56
SD	0.08	0.06	0.06	0.06	0.07	0.07	0.07	0.07
Max	1.25	1.31	1.41	1.50	1.56	1.60	1.63	1.68
Min	1.01	1.14	1.22	1.28	1.32	1.35	1.37	1.40

For any predictions of decompression requirements if a standby diver were to subsequently dive again, it is better to take the minimum observed PiO_2 values rather than the average to be on the conservative side. In addition, these might be more realistic since the observed experimental PiO_2 values (Annex A) appear to be higher than would normally be expected from CUMA operations at 9 msw (ranging from 1.5 to 1.8 ATA instead of from 1.5 to 1.7 ATA).

3.2 Repetitive dive considerations for the standby diver

Repetitive dive calculations were carried out for a number of situations to determine what the decompression requirements would be if the standby diver were to dive again as a working CUMA diver. Table 3 shows the inert gas loading calculated for different times at 9 msw and different TWA PiO_2 relative to the pre-dive baseline value. Since the standby diver will be staying a minimum of 30 min at 9 msw, the inspired TWA PiO_2 can be assumed to be greater than 1.35 ATA. At this PiO_2 level, the diver can be considered to be “clean” after approximately 30 min on the surface after the dive. Although the uptake and elimination of helium (He) and nitrogen (N_2) are calculated independently, the decompression requirements are based on the total inert gas load, i.e., the sum of the He and N_2 partial pressures. At higher PiO_2 levels, there will be a greater washout of N_2 and the diver can be considered “clean” earlier. For example, if the TWA PiO_2 after 30 min at 9 msw is 1.4 ATA, the diver can be considered “clean” 20 min after surfacing, and at 1.5 ATA, 10 min after surfacing (Annex A). Staying at 9 msw longer also improves the situation since the N_2 washes out at a faster rate than He is taken up. Thus, for normal standby diver operations where the diver is at 9 msw for 30 min or more, the diver should be able to dive again as a working CUMA diver after 30 min on surface, using CF Table 11 or 12. The diver can also continue to dive again as a standby diver any number of times instead of as a working CUMA diver since the exposure at 9 msw is a no-decompression dive.

Table 3. Total inert gas load compared to base-line pre-dive value

Time for standby dive (min)		TWA PiO ₂	Time on surface after standby dive (min)				
12 msw	9 msw		0.5 hr	1hr	2 hr	3 hr	4 hr
5	5	1.1	+	+	+	+	0
5	10	1.1	+	+	+	+	0
5	10	1.2	+	+	+	0	0
5	10	1.3	+	+	+	0	0
5	15	1.3	+	+	0	0	0
5	20	1.3	+	+	0	0	0
5	30	1.3	+	+	0	0	0
5	30	1.35	+	0	0	0	0
5	30	1.4	0	0	0	0	0

+ Total inert gas load greater than baseline pre-dive level

0 Total inert gas load equal to or less than baseline pre-dive level

If there is occasion for the standby diver to go down to 9 msw for a shorter period of time than 30 min, Table 3 shows that the diver may not be clean depending on the TWA PiO₂. After 3 hours, the standby diver can be considered a clean diver but at 3 hours for very short bottom times, the inert gas load is still greater than the pre-dive value, but it is minimal. Although the additional decompression required would also be minimal, if a dive within 3 hours is necessary, the standby diver should dive on CF Table 14 in the interest of safety. On the other hand, during live MCM operations where urgent completion of the mission is required, the diver can be considered a “clean diver” after one hour, even with less than 30 min spent during the dive at 9 msw. In this case, the dive supervisor must accept that there is a marginally higher risk of decompression sickness.

3.3 Oxygen toxicity considerations

A possible concern for a standby diver who subsequently performs a working CUMA dive is oxygen toxicity. If the second dive is a deep, long dive, the total oxygen exposure consisting of that from the standby dive and the CUMA dive, including 100% O₂ exposures at both the 9-msw in-water stop, and 12-msw surface decompression stop can be quite high. The whole body oxygen exposure can be estimated from the oxygen tolerance unit (OTU) [8, 9]. The maximum standby dive with 95 min spent at 9 msw will give about 200 OTUs. If the standby diver subsequently carries out an 81 msw/20 min surface decompression with oxygen dive from CF Table 12, it will result in another 350 OTUs [3], for a total of 550 OTUs. This is still below the daily recommended limit of 850 OTUs [8] and the average daily dose of 620 for three consecutive days of diving (Annex A).

4 Summary

The results of this study have shown that because of the high inspired levels of oxygen that the standby divers will be breathing at 9 msw when accompanying a working CUMA diver during the 9 msw in-water oxygen decompression stop, the inert gas loading will not be significant providing the standby diver spends at least 30 min at 9 msw. If necessary, the standby diver can dive again as a working CUMA diver using CF Table 11 or 12 as a “clean” diver after 30 min on the surface. If the standby diver stays less than 30 min at 9 msw, the inert gas load may be higher than the pre-dive value and if the standby diver were required to dive again within 3 hours after surfacing, then CF Table 14 should be used. After 3 hours, CF Table 11 or 12 can be used.

Thus, the procedure of adding bottom times to determine the decompression requirements of a second dive is no longer necessary. The standby diver can then be available for a subsequent dive to deeper depths. Alternatively, the standby diver can continue to dive again as a standby diver any number of times instead of as a working CUMA diver. This will increase the operational ability of a small dive team to continue diving operations and make better use of the diving personnel.

The above can be summarized by the following rules:

- (1) If at least 30 min at 9 msw have been completed, the standby diver may dive again after 30 min using CF Tables 10, 11 or 12.
- (2) If for any reason, less than 30 min at 9 msw have been completed and it is necessary to dive again within 3 hours, the standby diver must use CF Table 14. After 3 hours, the diver is clear to dive again as at (1) above.
- (3) During live MCM operations (not exercises) where operational tempo and completion of the task are urgent, the standby diver can be considered a “clean” diver after one hour, even if less than 30 min has been completed during the dive at 9 msw. In this case, the supervisor must be aware, and accept, that a marginally higher risk of decompression sickness exists.
- (4) The standby diver can continue to dive again as a standby diver any number of times

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Annex A Experimental Results and Analysis

A.1 Description of data acquisition system

The partial pressures of inspired O_2 (PiO_2) and inspired CO_2 ($PiCO_2$) were continuously monitored for all subjects on CUMA for the full duration of each dive. The PO_2 of the gas supplied to the breathing loop, as measured by the CUMA oxygen analyzer (Carleton Life Support Technologies, Inc., Part No. 1135-C), was also monitored for comparative analysis against PiO_2 . Data were acquired using a custom application developed in Labview (National Instruments) and HP Basic on a Sun Microsystems Ultra Sparc workstation through a IEEE 488 interface to an HP3852A Data Acquisition/Control Unit. The inspired gas in the breathing loop was sampled by penetrating the right side of the scrubber housing and extending a sample line (Parflex N 1/8 inch O.D. x 0.031 inch I.D., Nylon 11 tubing) between 20 to 40 mm up the inhalation breathing hose. Electrical leads monitored the CUMA oxygen analyzer PO_2 . The CUMA oxygen analyzer PO_2 was measured by teeing into the analyzer display cable. All gas sample lines and electrical leads from both Red and Yellow Divers and the standby diver were passed through a protective jacket of polyurethane tubing and then routed to a terminal block and diverted through the DRF hull.

Once outside the chamber, the gas samples were allowed to expand to atmospheric pressure and the samples diverted to the gas analysis instruments. The sample flow was kept constant using mass flow controllers (Brooks, Model 5850E, 0-1.0 L/min STPD¹ air) calibrated and set between 0.40 and 0.45. The PiO_2 was measured using furnace type O_2 analyzers (Ametek Oxygen Analyzer S-3A/1) and the $PiCO_2$ was measured using infrared analyzers (Analytical Development Company, PM3A). All lines from the instruments and the electrical leads from the chamber were interfaced to the HP3852A. The PiO_2 , CUMA oxygen analyzer PO_2 , $PiCO_2$, ergometer workload settings, time and depth (from the electronic depth transducer, Heise Model # 901B) were sampled every 6 seconds by the HP3852A system. The analogue output of the oxygen analyzers was also displayed on the PC-based dive computer located at the Dive Control Console.

A.2 Observed PiO_2

Figures A-1 to A-4 show the PiO_2 observed for each of the dive subjects for the four dives conducted during this study. The maximum PiO_2 for several of the divers was higher than expected, around 1.8 ATA. The normal expectation would be for the maximum PiO_2 to reach the PO_2 level being supplied by the set into the breathing loop (1.6 ± 0.1 ATA). Hence, the average results presented here may be too high for normal standby diver operations.

¹ All flow rates are referenced to 0 C and 101.3 kPa, dry gas, i.e., standard temperature and pressure, dry (STPD) unless indicated.

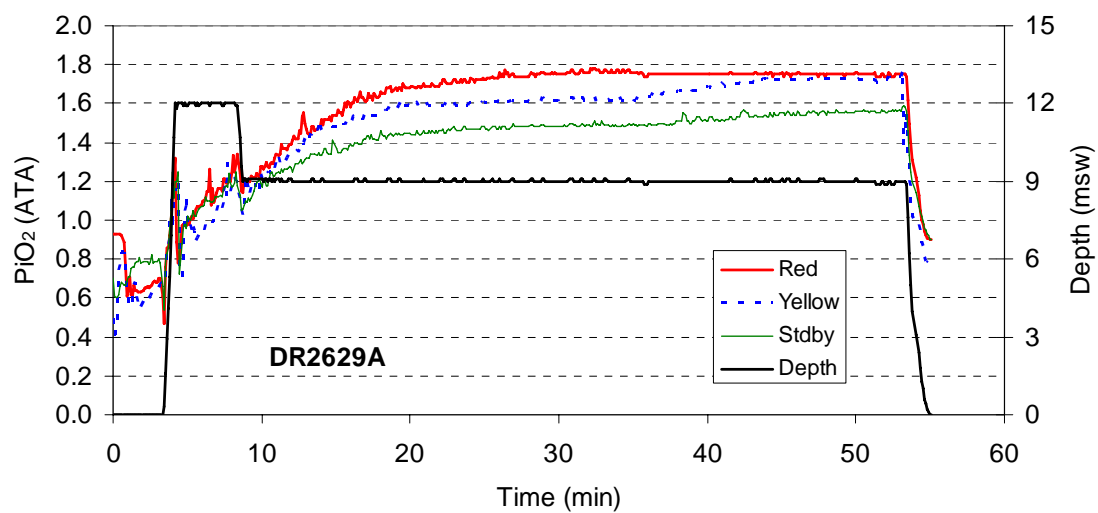


Figure A-1. Inspired PO_2 (PiO_2) for subjects in dive DR2629A

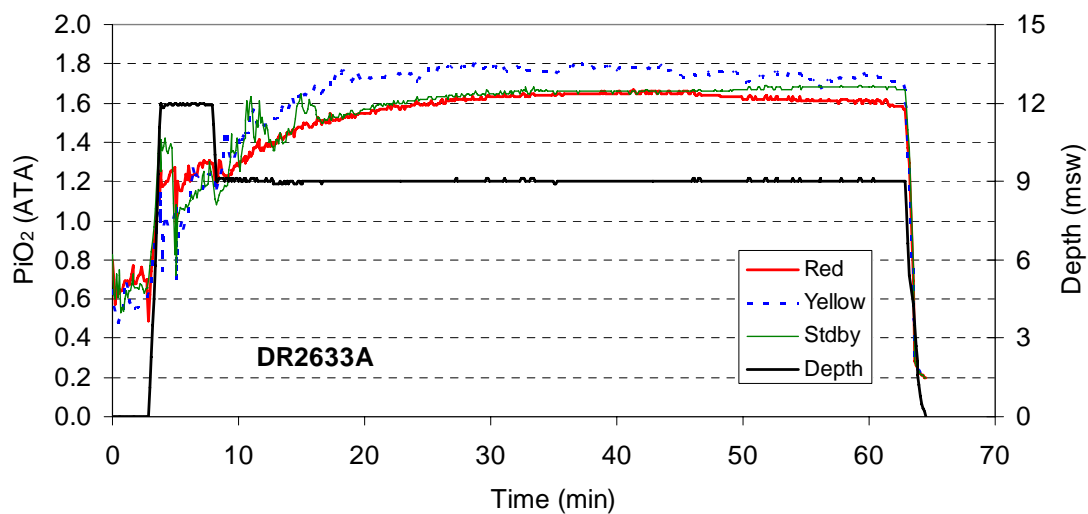


Figure A-2. Inspired PO_2 (PiO_2) for subjects in dive DR2633A

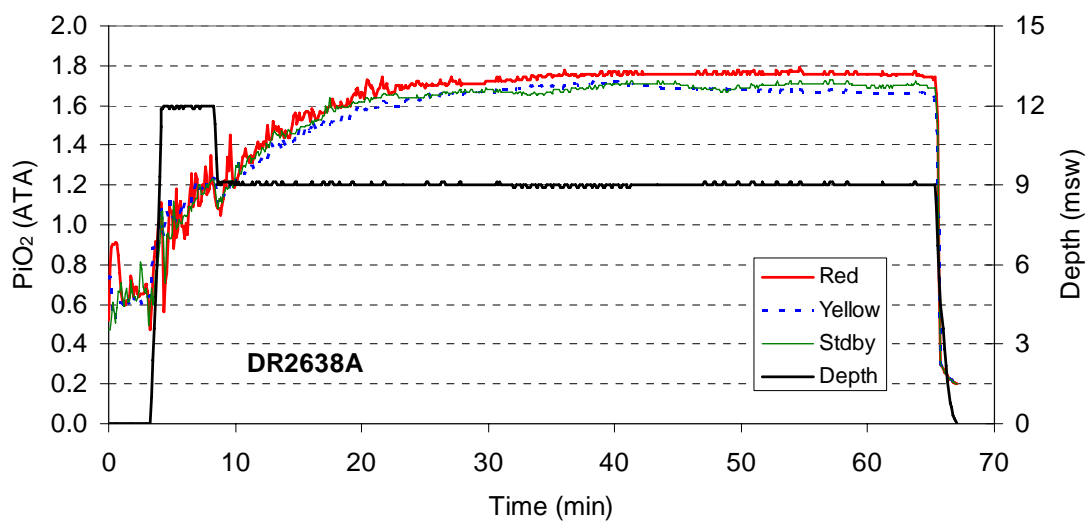


Figure A-3. Inspired PO_2 (PiO_2) for subjects in dive DR2638A

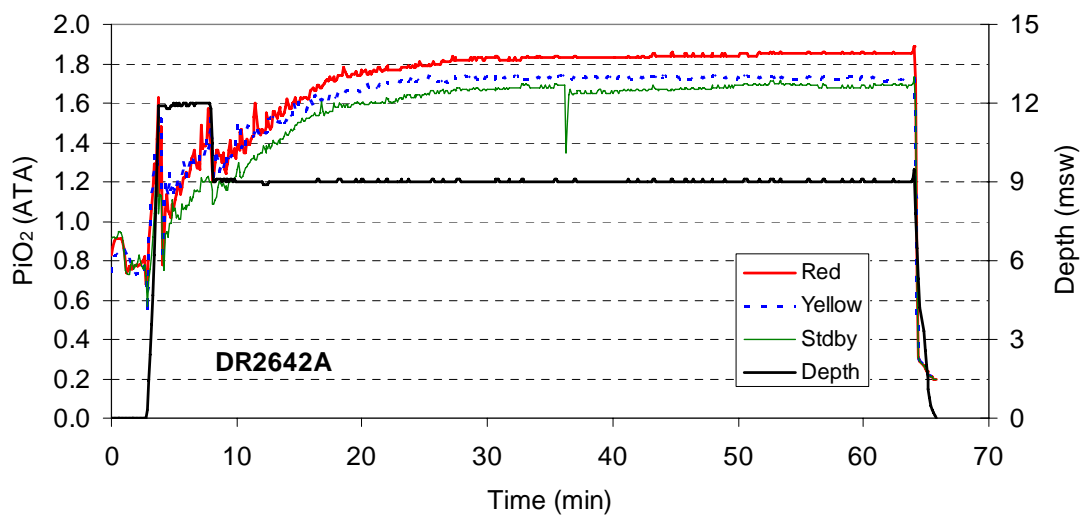


Figure A-4. Inspired PO_2 (PiO_2) for subjects in dive DR2642A

A.3 Repetitive dive calculations for the standby diver.

Figures A-5 to A-8 show the inert gas loading (P_{He} and P_{N_2} , partial pressures of He and N_2 , respectively) in the first two compartments of the decompression model that was used to generate the CUMA decompression tables. Although the uptake and elimination for each gas are calculated independently, the decompression requirements are determined by the total inert gas load P_T (i.e., $P_{He} + P_{N_2}$, the sum of the partial pressures). The values are shown for dives where the standby diver spends 5, 15, 30, and 95 min at 9 msw, and for three hours breathing air after returning to surface. For 5 min at 9 msw with a TWA PiO_2 of 1.1 ATA (Fig. A5), the total inert gas is still higher than the pre-dive baseline value (approximately 0.8 ATA) at the end of three hours. However, this time becomes shorter as the time at 9 msw increases and the TWA PiO_2 level becomes higher.

Table A-1 shows the time required for the total inert gas load to reach the pre-dive baseline value (and when the diver can be considered “clean”) after different times at 9 msw for the range of expected TWA PiO_2 . At higher PiO_2 levels, there will be a greater washout of N_2 . For example, if the TWA PiO_2 after 30 min at 9 msw is 1.3 ATA, the time required is 40 min, whereas at 1.4 ATA, the time is 20 min. Based on the experimental results, the TWA PiO_2 should be around 1.35 ATA, hence, the diver should be able to dive again as a “clean” diver after 30 min. Staying at 9 msw longer also reduces the time required to reach pre-dive values, particular at the higher PiO_2 levels when the N_2 washes out at a faster rate than He is taken up. At 1.5 ATA, the total inert gas load returns to pre-dive levels after about an hour at 9 msw.

Table A-1. Time required (after end of dive) to reach pre-dive baseline inert gas load

Standby dive		Time on surface (in min) after standby dive for given TWA PiO_2				
12 msw	9 msw	1.1 ATA	1.2 ATA	1.3 ATA	1.4 ATA	1.5 ATA
5	5	230	200	150		
5	10		190	140	30	
5	15		190	120	30	
5	20			50	30	20
5	30			40	20	10
5	95			30	10	-40

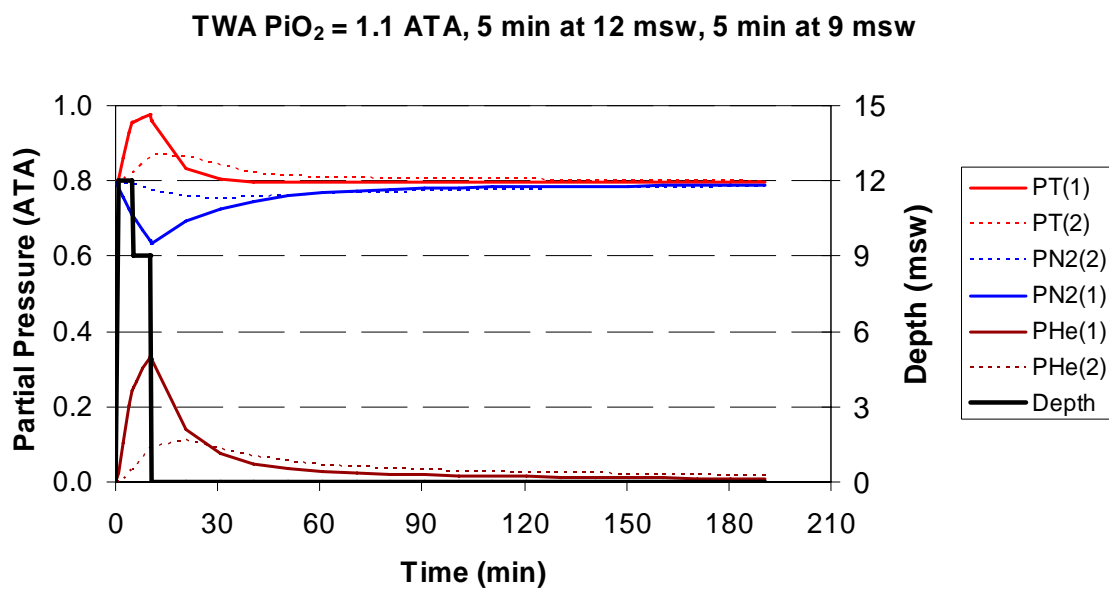


Figure A-5. Computed inert gas loading in first and second compartments for 5 min at 9 msw

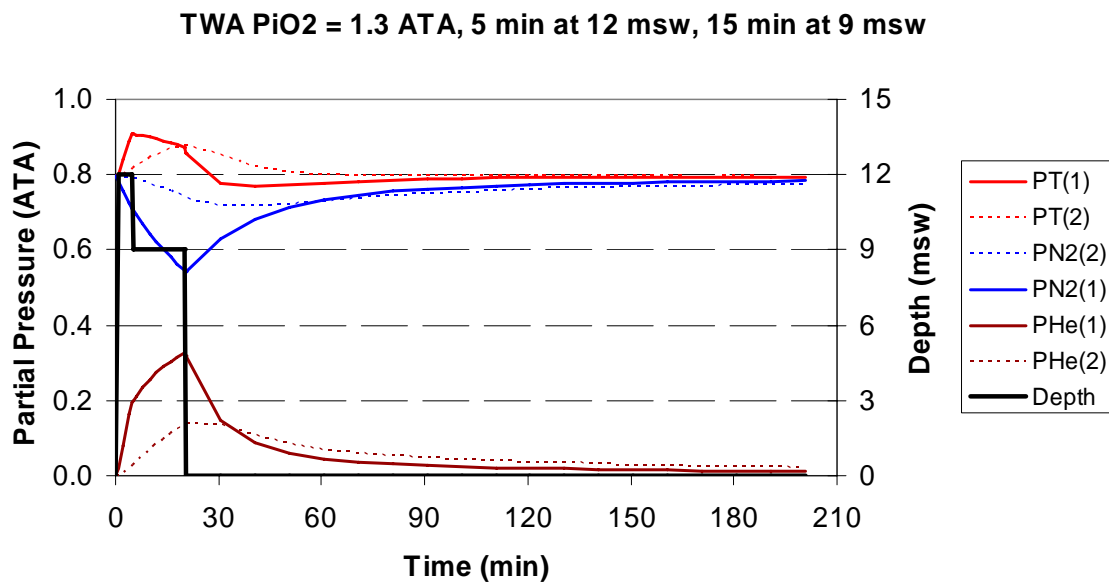


Figure A-6. Computed inert gas loading in first and second compartments for 15 min at 9 msw

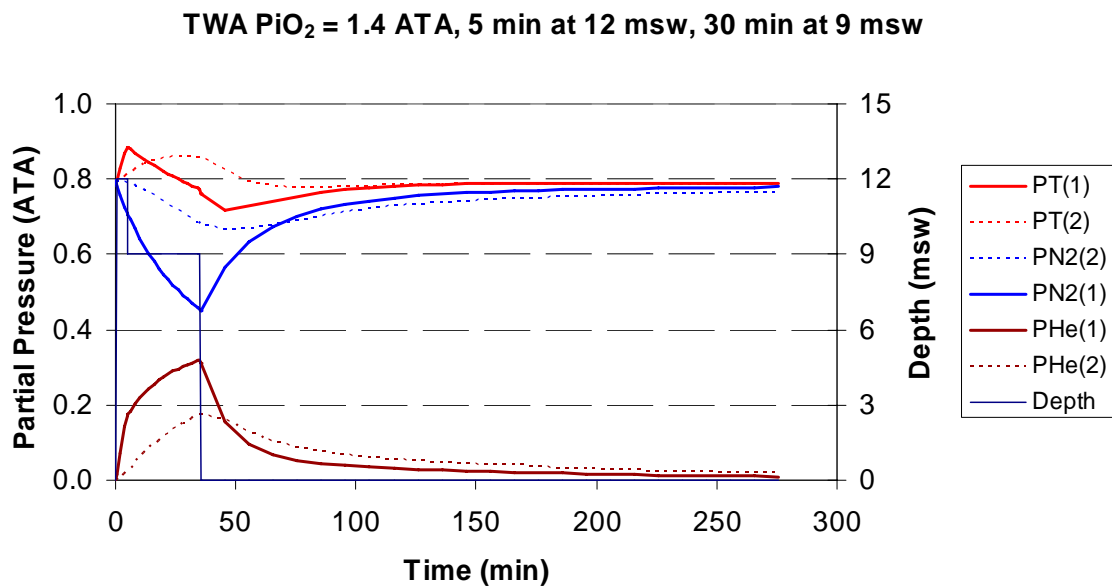


Figure A-7. Computed inert gas loading in first and second compartments for 30 min at 9 msw

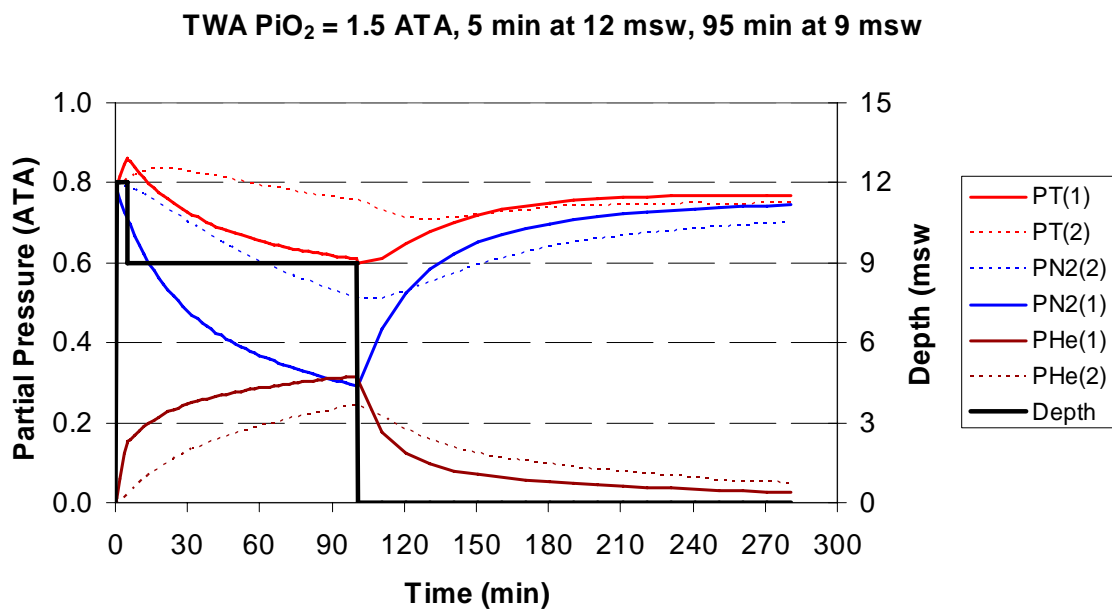


Figure A-8. Computed inert gas loading in first and second compartments for 95 min at 9 msw

A.4 Whole body oxygen exposure limits

The whole body OTU for a dive exposure can be calculated from

$$OTU = \Delta t((PiO_2 - 0.5) / 0.5)^{0.83}$$

where Δt is the time of exposure in minutes and PiO_2 is in ATA [8]. This approach, known as the Repex method, was developed for the control of daily high oxygen doses on a multiday basis. The term “whole body” includes not only pulmonary symptoms but a number of other symptoms such as paresthesia, headache, dizziness, nausea, effect on eyes, and reduction in aerobic capacity [9]. The threshold below which no symptoms develop has been assumed to be 0.5 ATA. Table A-5 gives the whole body operational exposure limits for seven consecutive days of diving.

Table A-2. Repex whole body oxygen exposure limits

Exposure (days)	Daily dose	Total OTU
1	850	850
2	700	1400
3	620	1860
4	525	2100
5	460	2300
6	420	2520
7	380	2660

Excerpted from References 7 and 8 – the Repex table allows up to 30 consecutive days of diving.

These daily limits take into account that a diver should be able to tolerate an additional exposure equivalent to a standard Table 6 treatment table (about 600 units) but with minor symptoms.

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List of symbols/abbreviations/acronyms/initialisms

DRDC	Defence Research & Development Canada
R&D	Research & Development
ATA	Atmospheres (absolute)
BMI	Body mass index
CF	Canadian Forces
CO ₂	Carbon dioxide
CUMA	Canadian Underwater Minecountermeasures Apparatus
DRF	Diving Research Facility
EDU	Experimental Diving Unit (now Experimental Diving and Undersea Group EDUG)
EDUG	Experimental Diving and Undersea Group
FDU(P)	Fleet Diving Unit (Pacific)
He	Helium
HeO ₂	Helium-Oxygen
HP	Hewlett-Packard
I.D.	Inside diameter
L/min	Litres/minute
MCM	Mine Countermeasures
min	minute
msw	metre of seawater
N ₂	Nitrogen
NATO	North Atlantic Treaty Organization
O ₂	Oxygen
O.D.	Outside diameter
OTU	Oxygen Tolerance Unit
PO ₂	Partial pressure of oxygen
PiCO ₂	Partial pressure of inhaled CO ₂
PiO ₂	Partial pressure of inhaled oxygen
PN ₂	Partial pressure of nitrogen
P _T	Total partial pressure of inert gases (helium and nitrogen)
RAN	Royal Australian Navy
RN	Royal Navy
STPD	Standard temperature and pressure dry
TWA	Time-weighted average

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(U) The Canadian Underwater Minecountermeasures (MCM) Apparatus (CUMA) is a self-contained, semi-closed circuit breathing apparatus in service with the Canadian Forces (CF) and other North Atlantic Treaty Organization (NATO) Navies for MCM diving to a depth of 81 metres of seawater (msw) using a mixture of helium and oxygen. Current CF rules state that a diver completing more than 30 minutes (min) of oxygen decompression has to be accompanied by a standby diver at the 9 metre decompression stop. As there are no specific repetitive diving rules governing such shallow dives on CUMA, the procedure of adding bottom times to determine the decompression requirements of a second dive must be used. As a result, the standby diver may become unavailable for a subsequent dive to deeper depths. This affects the operational ability of a small team to continue diving as the divers, including the standby become 'dived out' too quickly. Experimental dives to 9 msw to simulate a standby diver accompanying a CUMA diver were conducted in the DRDC Toronto Dive Research Facility to measure the inspired partial pressure of oxygen (PiO₂). The results showed that the time-weighted average PiO₂ after 30 min at 9 msw was greater than 1.3 atmospheres (absolute) (ATA). As a result, the inert gas loading should be minimal and there should be little or no decompression penalty associated with the standby diver diving again as a working CUMA diver. This will increase the operational ability of a small dive team to continue diving operations.

(U) L'appareil canadien de déminage sous-marin (ACDSM) est un appareil respiratoire autonome à circuit semi-fermé utilisé par les Forces canadiennes (FC) et par d'autres marines de l'Organisation du traité de l'Atlantique Nord (OTAN) pour effectuer des opérations de déminage sous-marin jusqu'à une profondeur de 81 mètres d'eau de mer. Cet appareil fournit un mélange d'hélium et d'oxygène. À l'heure actuelle, les règlements des FC stipulent que tout plongeur devant effectuer plus de 30 minutes de décompression à l'oxygène doit être accompagné par un plongeur en alerte au palier de décompression de neuf mètres. Puisqu'il n'existe aucune réglementation spécifique régissant les plongées successives d'aussi faible profondeur avec l'ACDSM, il faut utiliser la procédure qui consiste à additionner les temps de plongée pour déterminer le temps de décompression requis lors de plongées successives. Par conséquent, il se peut donc que le plongeur en alerte ne puisse effectuer de plongée subséquente à de plus grandes profondeurs. Cela a un impact négatif sur la capacité opérationnelle d'une petite équipe, puisque les plongeurs, y compris les plongeurs en alerte, atteignent trop rapidement le maximum permis. Pour simuler un plongeur en alerte accompagnant un plongeur utilisant un ACDSM, des plongées d'essai ont été effectuées à neuf mètres d'eau de mer à l'Installation de recherche en plongée de Recherche et développement pour la défense Canada – Toronto dans le but de mesurer la pression partielle d'oxygène inspiré (PiO₂). Les résultats ont démontré que la PiO₂ moyenne pondérée dans le temps était supérieure à 1,3 ATA (atmosphère absolue) après 30 minutes à neuf mètres d'eau de mer. L'accumulation de gaz inerte devrait donc être minimale et se traduire par une pénalité de décompression faible ou nulle pour un plongeur en alerte

effectuant une plongée subséquente avec un ACDSM. La capacité opérationnelle d'une petite équipe de plongée s'en trouve ainsi augmentée.

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(U) Mine countermeasures; breathing apparatus; standby diver; repetitive diving

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